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A DIGITAL AUDIO LINK TO THE CHANNEL ISLANDS IN THE UHF TELEVISION BAND:

Preliminary experimental results

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A DIGITAL AUDIO LINK TO THE CHANNEL ISLANDS IN THE UHF TELEVISION BAND : PRELIMINARY EXPERIMENTAL RESULTS

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Summary

A digital link at UHF has been proposed as a means of feeding radio programmes over the long sea path to the Channel Islands. An experimental link has been installed to test the viability of such a proposal. Results from the first five months of operation are presented in this Report.

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A DIGITAL AUDIO LINK TO THE CHANNEL ISLANDS IN THE UHF TELEVISION BAND: PRELIMINARY EXPERIMENTAL RESULTS

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1. INTRODUCTION

The Band II VHF/FM transmitter at Rowridge is scheduled for re-engineering. To comply with the agreements reached at the 1984 ITU Regional Administrative Radio Conference on VHF Broadcasting the aerial radiation pattern will be modified to radiate a lower power towards France. The network radio feed to the Channel Islands is provided by a diversity arrangement whereby stereo signals are received from transmitters at both North Hessary Tor and Rowridge. The signal from North Hessary Tor is normally preferred but both are needed to ensure continuity of stereo service because of the occurrence of fading.

As a result of the change, the transmitter on the Channel Islands will effectively lose its Band II feed. An additional link is therefore required to replace it. A digital link has been proposed as a replacement and will be installed initially on an experimental basis. The proposed link uses one of the existing UHF high-gain receiving aerials on Alderney; these were installed to provide the television feed to the Channel Islands. The aerials receive horizontally polarised signals from the transmitter at Stockland Hill (in Devon) and so the digital feed will also be transmitted horizontally polarised from there. Channel 30 has been proposed for the link as the channel is within the range which are broadcast from Stockland Hill, and gives the minimum possibility of causing interference to both United Kingdom and French transmissions. It was proposed that the signal be radiated from the UHF station at Stockland Hill at a relatively low effective radiated power (e.r.p.) using a high gain aerial. The details governing the planning of this link are described in Ref. 1 and an experimental link has been installed.

Initially only one of the two carriers proposed for the link[1] has been implemented as this should be sufficient to test the viability of the link. The experimental link carries a digitally modulated carrier positioned 2.4 MHz above the normal position of Channel 30 vision carrier; the signal is modulated using the tamed-frequency-modulation (TFM)[2] technique. The data is a 2.048 Mbit/s pseudo-random digital bit stream. On Alderney the signal is received on a log-periodic aerial array and then amplified, down-converted and demodulated. The carrier power and bit-error ratio (b.e.r.) are monitored at the receiver along with the level of co-channel interference from PAL System-I broadcasts. These results are stored by computer on floppy-disc for subsequent processing.

The results describing the performance of the link are analysed each month. The performance of the link is measured in terms of the percentage of the time for which the link was operational and the percentage of completely error-free seconds. Statistical data of the field strength of the digital signal and the co-channel interfence from PAL System-I transmissions is also collected. This allows a comparison with predicted and previously measured field strengths to be made.

Data collected from the link for about four months over a five-month period has been analysed. The purpose of this Report is to summarise the findings and to compare them with the predicted values used to calculate the expected performance of the link.

2. EXPERIMENTAL MEASUREMENTS AND RESULTS

A block diagram of the experimental link between Stockland Hill and Alderney is shown in Fig. 1. The digitally modulated carrier is radiated at an e.r.p. of 250 W from the main station at Stockland Hill and is positioned 2.4 MHz above the normal position of vision carrier in Channel 30. Initially the data stream consists of a pseudo-random sequence which allows the error rate to be measured very accurately at the receiving end. The link will, however, transmit information as a scrambled NICAM-3[3] data stream, the purpose of the scrambling being to spread the spectrum of the radiated signal evenly across its occupied bandwidth.

On Alderney the signal is received, amplified, down-converted and demodulated. The number of errors occurring in the pseudo-random data sequence each second is recorded. The monitoring equipment at the receiver also records the level of the wanted signal and the level of co-channel PAL System-I interference. The power in a bit-rate bandwidth centered about the digital carrier frequency is measured from the receiver automatic gain control (a.g.c.) and this is taken to be the level of the wanted signal. This level is measured every 30 seconds. The level of co-channel interference is measured using a UHF field strength meter which measures the power in the synchronising pulses of a

PAL System-I transmission. This is also measured every 30 seconds. The number of errors is measured every second and if the bit-error ratio (b.e.r.) is above 1×10^{-4} then the link is deemed to have failed. The b.e.r. must drop to below 1×10^{-5} before the link is deemed to be operational again. The length of each link failure is recorded along with the number of outage seconds and error-free seconds. The number of digital errors in each 30-second period is also recorded.

3. RESULTS

The data recorded between the 7th June 1986 and the 29th October 1986 has been analysed. Data collected during two weeks in June and two weeks in July was not considered as the head amplifier on the aerial failed. The field strength statistics and the link performance are summarised in Tables 1 and 2 below:

Table 1

Field strength statistics for data recorded between: midday on 7/6/86 and midday on 29/10/86

Statistic	Digital signal (dBμV/m)	CCI signal (dBμV/m)
Mean	37.5	-14.5
Standard deviation	8.7	18.7
Maximum value	64.9	55.4
Minimum value	4.1	-
Correlation between signals	0.75	

The statistics involving the CCI signal required careful calculation as the signal was below the noise level for more than 60% of time. As a result, the mean and standard deviation were calculated from the 'best-fit' straight line to the data in the cumulative probability curve. The mean is therefore, strictly speaking, the predicted median assuming the CCI signal was broadcast for 100% time. The correlation was calculated using only data samples during which the CCI signal level was above the noise floor.

Table 2

Link performance statistics for data recorded between: midday on 7/6/86 and midday on 24/10/86

Performance criterion	Percentage of time
Link operational	97.8
Error-free seconds	89.5

The length of each link failure is shown in the histogram in Fig. 2. This shows that most of the failures are for short lengths of time. The cumulative probability curve is shown in Fig. 3; the solid lines show the measured field strengths, and the dotted lines are the field strengths predicted in Ref. 1.

4. DETAILED ANALYSIS AND DISCUSSION

A comparison between the measured and predicted field strength can best be obtained from Fig. 3. This shows that the wanted field strength is very similar to that predicted for the link from the original measured results. It should be remembered that this data was collected over four months and a longer timescale is required to produce statistically valid results for the link. An example of the necessity of a long timescale to ensure statistical validity is that these measured results include three days of the lowest UHF field strength noted on Alderney from Stockland Hill in ten years. This can be seen in the July field strength results, Fig. 4., where a very low field strength was exceeded for 99% time. In addition seasonal variation in both wanted and CCI signal levels can be expected to occur. It can be seen from Fig. 3 that for small percentages of time the field strength was 2 - 2½ dB lower than predicted and this would reduce the performance of the link. The extent of this reduction in performance can be predicted and this is shown for two particular values of field strength and hence carrier-to-noise ratio (C/N) in Table 3.

Table 3: Performance of the link at poor C/N ratios.

Field strength	Resulting C/N	Percentage time for which the given C/N ratio was exceeded	
		Predicted	Measured
16 dBμV/m	14 dB	99.87%	99.74%
18 dBμV/m	16 dB	99.80%	99.59%

As the demodulator requires a C/N of 14 dB to ensure a b.e.r. of less than 1×10^{-4} and a C/N ratio of nearly 16 dB to ensure a b.e.r. of less than 1×10^{-5} then the performance of the link could be expected to be about 0.2% worse than predicted. The level of PAL System-I co-channel interference can be seen to be lower than was predicted and the correlation between the two signals, Table 1, was considerably higher than the 0.5 value which was assumed[1]. As a result the performance of the link was less affected by interference than was predicted.

However, the link was found to be operational for only 97.8% of time as opposed to 99.55% of time

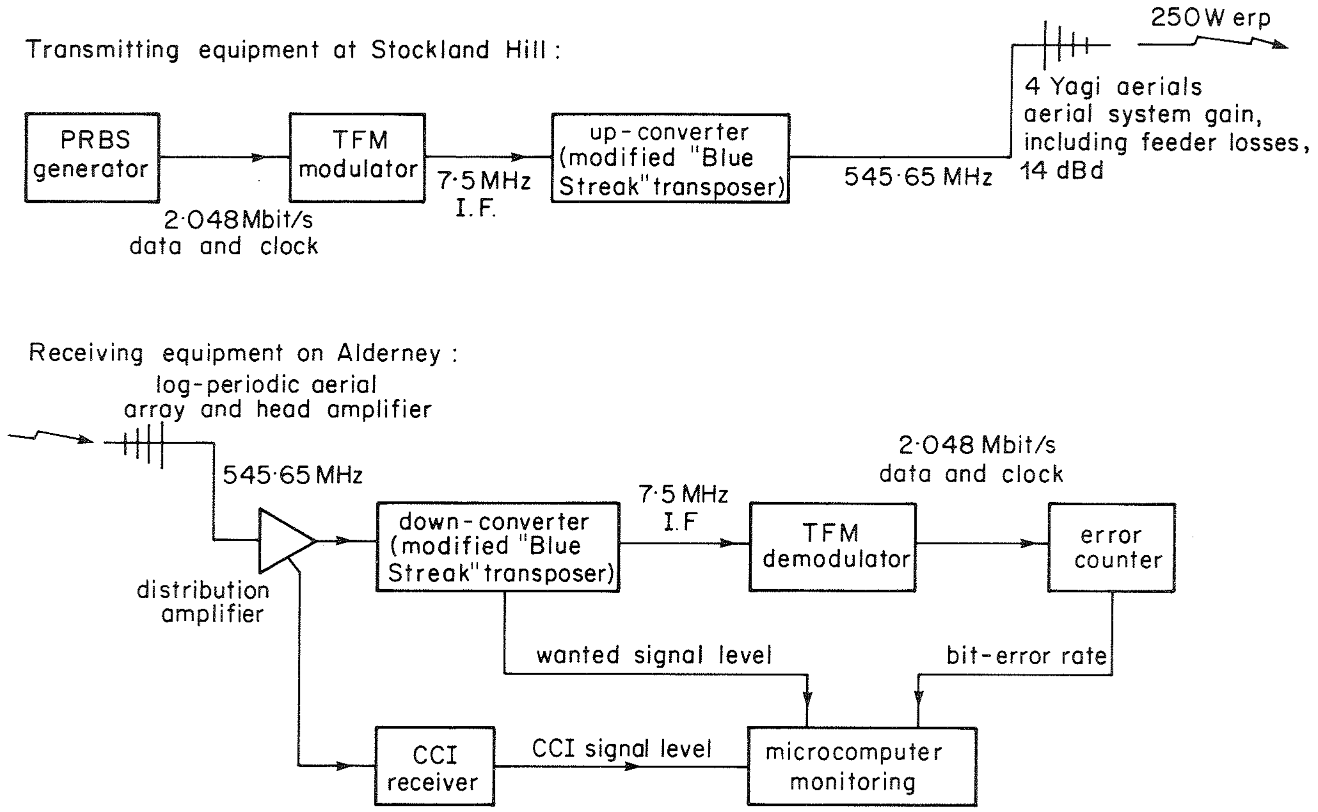

Fig. 1 - Block diagram of the experimental link equipment.

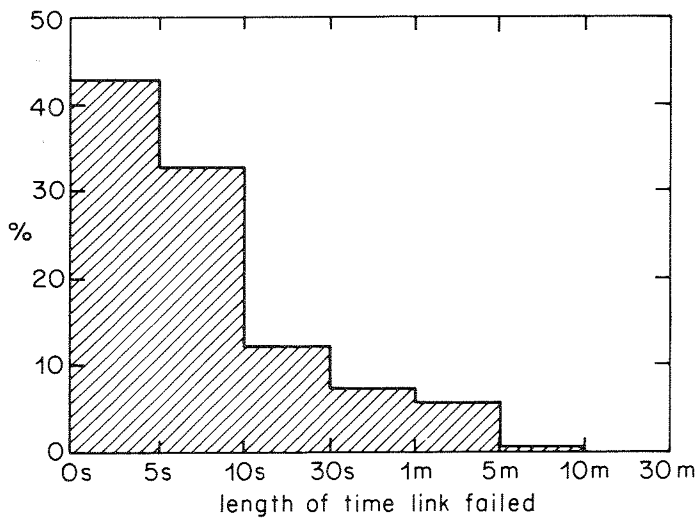

Fig. 2 - Histogram showing the length of time of each link failure as a percentage of the number of failures.

predicted from both C/N and carrier-to-interference ratio (C/I) considerations[1]. There are a number of possible reasons for the higher than expected link outage time; these are listed below:

(i) worse than expected C/N or C/I performance from the demodulator,

(ii) frequency selective fading due to long-delay multipath,

(iii) very fast signal variations, which are not recorded at the 30 second field strength recording rate, which results in deep fades not being recorded,

(iv) soft failure of the head amplifier, loss of lock in the carrier recovery or clock recovery circuit or other hardware failures,

(v) unexpected interference not from PAL System-I transmissions.

To examine the C/N and C/I performance of the demodulator a period of two days, 20th and 21st June, was examined in more detail. This period was chosen as about a third of all the outage seconds recorded over the first two-and-a-half weeks occurred during these two days. First the chart recording of the field strengths was examined and it was found that, whilst some of the link outage seconds could be attributed to poor C/N conditions, many of the link outage seconds occurred whilst there was a good C/N and C/I. The samples over this period were then examined by grouping them according to their C/N, C/I and number of digital errors over the 30 second period. The results are shown in Table 4 and are interesting; however, it should be remembered that the

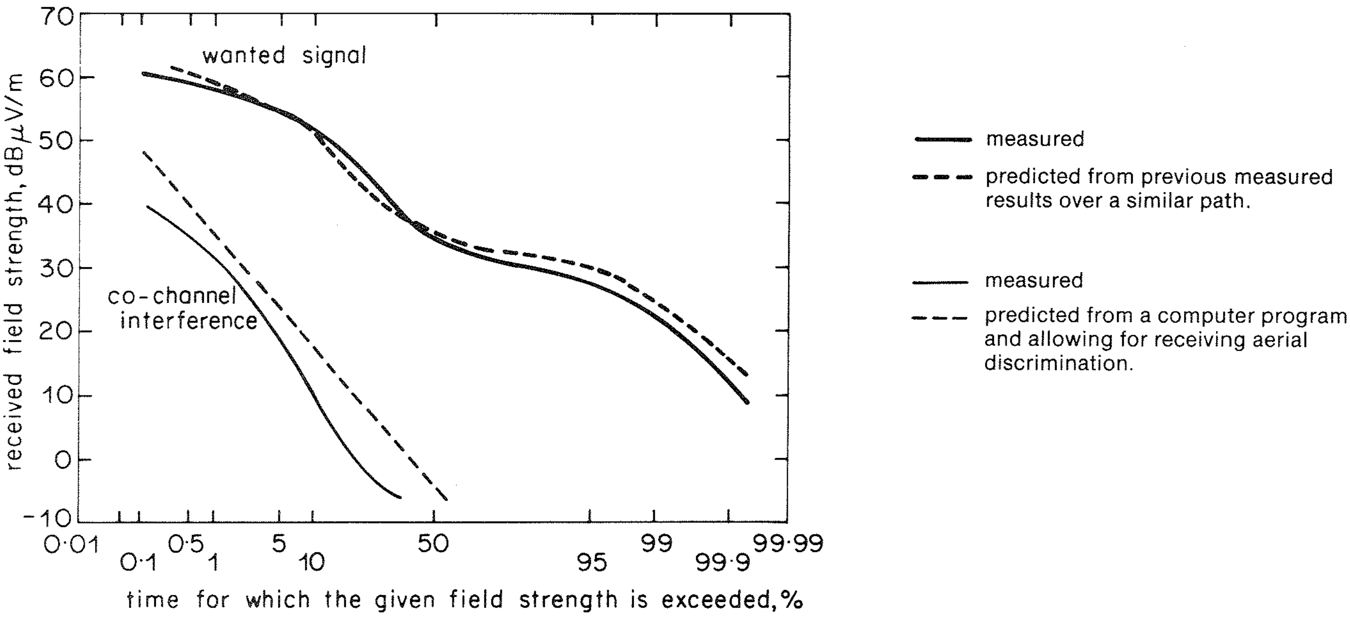

Fig. 3 - Cumulative probability curve for data collected between June and October 1986.

errors could have occurred at any point during the 30 second period but that the field strength was measured at the end of the period. The first table, (4a), represents essentially error free performance (a b.e.r. averaged over 30 seconds of less than 5 x 10^{-7}) and this condition occurred eight times with a signal with a *C/N* of between 16 dB and 18 dB. This shows that the *C/N* performance of the demodulator on site was close to its performance measured in the laboratory. By a similar argument it can be seen that the link is essentially error free at a *C/I* of between 5 dB and 10 dB. Whilst it does not prove that the link will operate with a *C/I* equal to the assumed protection ratio of 0 dB[1], it could easily be that a *C/I* of 0 dB without a fade at other times in the 30 second period did not occur over the two-day period measured. This was later shown to be the case from a similar analysis of a longer period. From these results it is reasonable to conclude that the *C/N* and *C/I* performance of the demodulator was essentially as measured in the laboratory.

Frequency selective fading due to long delay multipath would result in a high b.e.r. when the signal appeared to have a good *C/N* and *C/I*. This is consistent with the results in Tables 4(d) - 4(f) in which a high error rate was found to occur in the presence of a good *C/N* and *C/I*. However these results do need to be treated with a certain amount of caution as the errors could equally be due to a rapid deep fade earlier in the 30 second period and the signal could thus have recovered to a good *C/N* and *C/I* by the time the field strengths were measured.

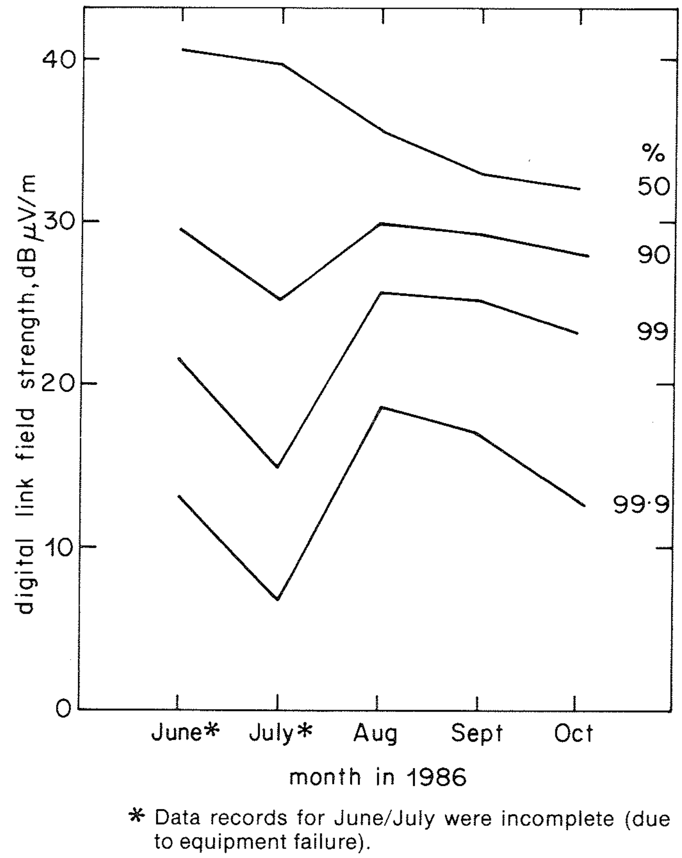

Fig. 4 - The field strength that was exceeded over various months for the given percentage of time.

At first sight, faster signal variations could explain the higher than expected error rate. These variations could result from deep fades due to short delay multipath. However, if a system is under-

Table 4
Number of instances of a C/N and C/I at each particular b.e.r.

C/N(dB)	C/I(dB) <0	0 - 5	5 - 10	10 - 15	15 - 20	>20
>20 dB	0	0	3	96	328	2215
18 to 20	0	0	2	1	0	31
16 to 18	0	0	0	0	0	8
14 to 16	0	0	0	0	0	0
12 to 14	0	0	0	0	0	0
<12	0	0	0	0	0	0

a) C/N vs C/I for b.e.r. corresponding to fewer than 3×10^1 errors in 30 seconds

C/N(dB)	C/I(dB) <0	0 - 5	5 - 10	10 - 15	15 - 20	>20
>20 dB	0	2	7	198	492	680
18 to 20	0	0	7	4	0	28
16 to 18	0	0	2	0	0	12
14 to 16	0	0	0	0	0	4
12 to 14	0	0	0	0	0	0
<12	0	0	0	0	0	0

b) C/N vs C/I for b.e.r. corresponding to 30×10^1 to 3×10^2 errors in 30 seconds

C/N(dB)	C/I(dB) <0	0 - 5	5 - 10	10 - 15	15 - 20	>20
>20 dB	1	2	13	222	326	507
18 to 20	0	0	13	7	0	34
16 to 18	0	0	3	0	0	10
14 to 16	0	0	0	0	0	9
12 to 14	0	0	0	0	0	3
<12	0	0	0	0	2	0

c) C/N vs C/I for b.e.r. corresponding to 3×10^2 to 3×10^3 errors in 30 seconds

C/N(dB)	C/I(dB) <0	0 - 5	5 - 10	10 - 15	15 - 20	>20
>20 dB	1	2	5	51	74	279
18 to 20	0	0	2	2	0	1
16 to 18	0	0	1	0	0	4
14 to 16	0	0	0	0	0	2
12 to 14	0	0	0	0	1	1
<12	0	0	0	0	2	0

d) C/N vs C/I for b.e.r. corresponding to 3×10^3 to 3×10^4 errors in 30 seconds

C/N(dB)	C/I(dB) <0	0 - 5	5 - 10	10 - 15	15 - 20	>20
>20 dB	0	0	1	1	1	6
18 to 20	0	0	0	0	0	4
16 to 18	0	0	2	0	0	4
14 to 16	0	0	0	0	0	3
12 to 14	0	0	0	0	1	0
<12	0	0	0	0	3	0

e) C/N vs C/I for b.e.r. corresponding to 3×10^4 to 3×10^5 errors in 30 seconds

C/N(dB)	C/I(dB) <0	0 - 5	5 - 10	10 - 15	15 - 20	>20
>20 dB	0	0	0	0	0	7
18 to 20	0	0	0	0	0	2
16 to 18	0	0	0	0	0	5
14 to 16	0	0	0	0	0	7
12 to 14	0	0	0	0	0	1
<12	0	0	0	7	5	0

f) C/N vs C/I for b.e.r. corresponding to more than 3×10^5 errors in 30 seconds

sampled, then, assuming the measurement times are not correlated with the signal level, there is the same chance of a high signal strength (or a deep fade) being missed. Therefore the cumulative probability curve will be correct; this curve, shown in Fig. 3 shows that the wanted signal does not predict the percentage time the link was operational correctly. Therefore fast signal variations cannot be the cause of the higher-than-expected error rate. In any case, the analogue chart recordings shown in Ref. 4 do not greatly support this theory.

Hardware failure in some cases could result in a larger link outage time. A loss of lock in the carrier recovery or clock recovery circuits would result in an error ratio of 5×10^{-1}. More than 30 ms at this error rate would place the 30-second period in the fifth or sixth table in Table 4. Most of the entries in these tables are attributable to a poor C/N. It is unlikely that the loop would drop out of lock and then re-acquire lock in less than 30 ms. Therefore whilst this mechanism cannot be entirely eliminated it seems unlikely that it is the cause of the higher-than-expected

error rate. Most other forms of hardware failure would be recorded as a loss of wanted signal level and so would result in a significant distortion of the cumulative probability curve. The link performance calculated from the cumulative probability curve would be found to be in good agreement with the actual result, however as we have seen this is not the case.

Unexpected interference not due to PAL System-I transmissions is an unknown quantity. Such interference would certainly give rise to poor bit-error ratios in the presence of a good C/N and what appeared to be a good C/I. This is because the interference is measured by recording the power in the peak synchronising pulses of the PAL System-I waveform and as a result any unexpected interferer would not be measured if it had no power at the vision carrier frequency of Channel 30.

The most likely causes of the higher-than-expected error rate are thus frequency selective fading due to long delay multipath or in-band interference from a non-PAL System-I transmission. In both these cases the problem could be examined further by photographing the frequency spectrum of Channel 30 during times of high bit-error ratios.

5. CONCLUSIONS AND RECOMMENDATIONS

An experimental UHF digital link has been installed on an over-the-horizon sea path between Stockland Hill (in Devon) and Alderney, and the performance of the link for about four months over a five-month period has been measured and analysed; failure of a masthead amplifier prevented valid results from being obtained over the full period.

The measured field strengths were found to be very similar to the predicted levels for the link. However it should be noted that the measured results include three days of the lowest UHF field strength noted on Alderney from Stockland Hill in ten years. The correlation between the wanted and interfering signal field strengths was found to be higher than that assumed in the original calculations. As a result, the link should have achieved a reliability of better than 99.5% of time. However it was found to be operational for only 97.8% of time.

A number of mechanisms which might account for this shortfall in performance have been discussed and it can be concluded that frequency-selective fading or unexpected interference not from PAL System-I transmissions are the most likely causes of the discrepancy. Both these mechanisms should be investigated further.

It is recommended that possible methods of recording the frequency spectrum of Channel 30 on Alderney during times of high error rate be investigated, with a view to including this form of monitoring into the experiment. These results are based on data recorded during summer and autumn months which included known periods of particularly adverse propagation. As a result this data may well not be representative of the annual performance and several more months of data taken over the winter and spring periods should be obtained before drawing firm conclusions.

6. ACKNOWLEDGEMENT

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